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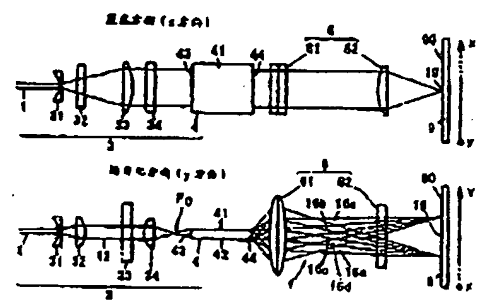
[54] 发明名称 激光束均匀照射的光学系统

[57] 摘要

激光束均匀照射的光学系统，包括：把来自光源的激光束在空间上分割为分割束的波导；把分割束重合照射在照射面上的重合用透镜；使照射面上的光束强度均匀的延迟板。波导使分割束宽度为激光束截面上的空间干涉距离的 1/2 倍以上；延迟板使分割出的彼此相邻的分割束间延迟比该激光束的时间的干涉距离还长，减轻照射面上的干涉。另一光学系统包括：把激光束分割为分割束的激光束分割部件；把分割束重合照射在照射面上的重合照射部件；使照射面上的光束强度均匀的均匀化部件。均匀化部件包括：使分割出的彼此相邻的分割束之间延迟比该激光束的时间的干涉距离还长的光学延迟部件，还可包括：使分割出的彼此相邻的分割束之间偏振方向实质上正交的旋光部件。



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OPTICAL SYSTEM FOR UNIFORM IRRADIATION OF LASER BEAM

Field of the Invention

The present invention relates to an optical system for uniform irradiation of laser beam which improves the uniformity of the intensity distribution of the laser beam on an irradiated area during the laser treatment for an irradiated object.

Background of the Invention

As an example in which heat treatment by laser radiation is employed, the approach of forming the amorphous silicon film beforehand by the vapor deposition, such as CVD, on the suitable substrate, for example, a glass substrate, on the occasion of manufacture of the polysilicon film, and scanning and polycrystallizing this amorphous silicon film by the laser beam is learned. For example, the approach has been disclosed in U.S. Patent No. 5,529,951, in which the non-crystal was formed on the polysilicon layer by evaporating the amorphous silicon on the circuit intergrant again and irradiating the necessary locations with an excimer laser beam in the assembly of a semiconductor integrated circuit. This U.S. Patent has used a fly's-eye lens or a prism as an uniform unit to make the intensity distribution of the excimer laser beam on entire subquadrate area uniform in order to increase the irradiated area.

We also know the approach of polycrystallizing the silicon film on a large substrate, comprising for example, condensing the laser beam from a laser source on the amorphous silicon film with a lens and carrying out laser radiation during which the silicon film is made to be crystallized in the process of coagulation while melting locally. The distribution of axial intensity of the beam at an irradiated location is usually the Gaussian distribution with optically axial symmetry depending on a beam profile of the laser source. The polysilicon film formed by the irradiation of such a beam has a very low uniformity when crystallized in its surface direction, and therefore it is difficult to be used as a semiconductor substrate in the manufacture of a thin film transistor.

Furthermore, the technique is also known in which the excimer laser with short wavelength, the profile of which is made rectangle-like distribution on the irradiated area, is used to irradiate and heat the semiconductor film. In JP 11-16851 and JP 10-333077, the laser beam from an oscillator passes through two cylindrical lens arrays which intersect mutually in a surface perpendicular to an optical axis, and is imaged on the semiconductor film surface by disposing a focusing lens ahead. The cylindrical lens array is an optical element which divides a beam of light into a plurality of beams of light, in which a plurality of tiny cylindrical lenses are configured to be in parallel each other and vertical to the optical axis.

In above mentioned approaches, the laser beam which takes Gaussian distribution or takes pure pattern passes through two cylindrical lens arrays and the uniform intensity distribution can be got in two orthogonal directions. The shape of the irradiating beam on the semiconductor film surface has different widths in two orthogonal directions on the semiconductor surface. By this approach, the irradiating laser beam sweeps in width direction of the narrow side, thus the polycrystalline area with a constant width equivalent to that of the long side has been formed repeatedly on the

semiconductor film.

However if the laser beam from the laser source is divided by such a cylindrical lens array and then is superposed on the irradiated area, the optical interference of the laser beam will arise on the irradiated area, and thus the interference pattern with strong and weak intensity repeatedly will be formed.

Because the interference caused by the superposition of a plurality of beams on the irradiated area will affect the crystal growth on this area. That is, when the amorphous semiconductor film is heated and crystallized using a rectangle-like irradiating laser beam, since the irradiating beam is moving along the width direction of the narrow side, the intensity distribution of the length direction orthogonal to the moving direction influences the crystal growth greatly. The intensity distribution of this direction is nonuniform and the interference pattern is big, which is disadvantageous to the growth of the crystal grain of the silicon film.

Several approaches used to remove the nonuniformity of the irradiating intensity of the laser resulted in this interference have been proposed. In JP 2001-127003, an optical system has been disclosed, wherein the laser beam from a light source was made to be the collimated light by a collimator and irradiated a mirror with step-like reflecting faces, and the beams divided by this mirror passed through the cylindrical lens array for superposition and the cylindrical lens array for convergence and then irradiated the irradiated area. With the steps between each of the reflecting faces, this optical system establishes the optical path difference larger than the interference length of the laser beam for the divided beam, thus preventing the interference between the divided beams on the irradiated area.

In addition, JP 2001-244213 has disclosed the technique, in which the laser beam from the light source was made to be the collimated light by the collimator and irradiated a plurality of tiny mirrors, and the reflected lights from each of mirrors irradiated the irradiated area and were superposed, thus preventing the interference by guaranteeing the optical path difference of the laser beam reflected by each of plane mirrors above the interference length.

The above mentioned technique for beam uniformity uses the mirror with a plurality of reflecting faces to establish the optical path difference so as to prevent the interference arising when the laser beam from the same light source is divided and then superposed on the irradiated area, but these optical systems require the special mirror. In particular, the optical system in JP 2001-244213 requires the configuration that makes the optical axis of the optical system based on the mirror bent. In order to enable each of the divided beams to irradiate the irradiated area accurately, it is required that each of mirrors in the optical system meet the special position relationship. Therefore, the configuration with a plurality of mirrors becomes complex and there is a problem that the degree of freedom of the optical system configured as heat treatment device is reduced. Especially, when the optical path difference is established for all of the divided beams, for the laser oscillation source with large temporal interference distance, the device will become huge and complex, which is impractical and difficult for optical adjustment.

Summary of the Invention

In view of above described problem, the object of the present invention is to provide an optical system for uniform irradiation of laser beam, which divides the laser beam from a light source and makes the divided beams superposed on the irradiated area and then forms the uniform intensity distribution of the irradiating beam on the irradiated area. It can prevent the interference between the divided beams caused by superposition and obtain the uniformity of the irradiating beam.

The another object of the present invention is to provide an optical system for uniform irradiation, which is used to prevent such a interference and makes the structure and adjustment of the uniformity of the irradiating beam simple and easy.

The still another object of the present invention is to provide an optical system, which is suitable for being a laser heating device to polycrystallize the amorphous silicon film in a irradiated object when irradiating it and can form the amorphous silicon film with less defects on the crystalline area.

The optical system for uniform irradiation of laser beam according to the invention consists of the following parts: a laser beam division unit which divides the laser beam from a laser source into a plurality of divided beams spatially in the beam cross section; a superposition and irradiation unit which makes a plurality of the divided beams superposed and irradiated on the irradiated area; and an uniformity unit which makes the intensity of the beam on the irradiated area uniform. The laser beam division unit enables the divided beam to have a width of more than 1/2 times of the spatial interference distance in the direction of the cross section of the laser beam from the light source. Even though the divided beams defined by such a beam width are superposed on the irradiated area by means of the superposition and irradiation unit, it can also alleviate the mutual interference among a plurality of beams so that the intensity distribution on the irradiated area is uniform.

In addition to the laser beam division unit which can divide the laser beam from the laser source into a plurality of the divided beams spatially in the beam cross section and the superposition and irradiation unit which makes a plurality of the divided beams superposed and irradiated on the irradiated area, this optical system for uniform irradiation of laser beam further comprises the uniformity unit which makes the intensity of the beam on the irradiated area uniform. A type of the uniformity unit comprises an optical delay unit which makes one of the adjacent divided beams relative to the other be delayed a longer distance than the temporal interference distance of the laser beam. The optical delay unit is used to prevent the interference occurring between the adjacent divided beams on the irradiated area and make the intensity distribution of the beam uniform.

The other uniformity unit according to the present invention comprises an optical rotatory unit which makes a polarization angle between the adjacent divided beams divided by the laser beam division unit essentially orthogonal. By making the polarization angle between the divided beams mutually orthogonal, the optical rotatory unit can alleviate the interference between the divided beams occurring when superposing each of the adjacent divided beams on the irradiated area, so as to make the intensity distribution of the irradiation uniform.

The optical system according to the present invention has the advantage of making the intensity distribution of the irradiation uniform extremely because it can reduce the factor about the spatial interference distance in the direction of the cross section of the laser beam and the factor about the temporal interference distance in the direction of the optical axis at the same time.

The superposition and irradiation unit according to the present invention can make the divided laser beams be shifted or misaligned each other on the irradiated area so as to form the duplicated irradiating beams. When each of the divided beams divided by the laser beam division unit pass through the superposition and irradiation unit, they will be optically misaligned and irradiate the irradiated area, which will reduce the interference between the divided beams on the irradiated area. The superposition and irradiation unit for duplicated shift or misalignment can be simply performed, which can reduce the interference caused by the factor about the spatial interference distance and the factor about the temporal interference distance in the direction of the optical axis at the same time.

The optical system for uniform irradiation of laser beam according to the present invention can take the irradiated area as a semiconductor film formed on a noncrystal or polycrystal in a substrate and can use the semiconductor film to anneal.

Detailed Description of the Drawings

The accompanying drawings will be described briefly as follow.

Fig. 1A and 1B are schematic diagrams illustrating the configuration of an optical system for uniform irradiation of laser beam using a waveguide according to an embodiment of the present invention, which represent the diagrams viewed from y-direction and x-direction respectively.

Fig. 2 is a cross section view illustrating the division form of the laser beam in the waveguide.

Fig. 3A illustrates the configuration of the divided beams in the cross section of the laser beam when the laser beam is divided in the waveguide; Fig. 3B illustrates the configuration of the divided beam at the exit face of the waveguide.

Fig. 4 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when two adjacent divided beams divided by the waveguide are superposed on the irradiated area (d=s).

Fig. 5 is a schematic diagram illustrating the definition of the spatial interference distance of the laser beam.

Fig. 6 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when 7 divided beams divided by the waveguide are superposed on the irradiated area (d=s).

Fig. 7 is a graph of the optical path difference versus the visibility of the laser beam.

Fig. 8A and 8B are schematic diagrams illustrating the configuration of an optical system for uniform irradiation of laser beam using a cylindrical lens array as a laser beam division unit according to the other embodiment of the present invention, which are equivalent to Fig. 1A and 1B.

Fig. 9A illustrates the configuration of the divided beams in the cross section of the laser beam when using the cylindrical lens array as the laser beam division unit; Fig. 9B also illustrates the configuration of the divided beam at the exit face of the waveguide.

Fig. 10 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when two adjacent divided beams divided by the cylindrical lens array are superposed on the irradiated area (d=s).

Fig. 11 is a graph illustrating the intensity distribution and visibility of the superposed irradiating beam when 7 divided beams divided by the cylindrical lens array are superposed on the irradiated area (d=s).

Fig. 12A and 12B are schematic diagrams illustrating an optical system for uniform irradiation of laser beam using a waveguide as a laser beam division unit and a retardation plate with light transmission as an optical delay unit according to an embodiment of the present invention, which are similar to Fig. 1A and 1B.

Fig. 13 is a variant example of the optical system shown in Fig. 12, which illustrates an optical system obstructing the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through; it's similar to Fig. 12B.

Fig. 14 is a schematic diagram illustrating the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention, which is similar to Fig. 12B.

Fig. 15 is a schematic diagram illustrating the laser beam division in the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide, which is similar to Fig. 14.

Fig. 16A and 16B are schematic diagrams illustrating the division state of the laser beam in the waveguide with the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide as shown in Fig. 15; they are similar to Fig. 3A and 3B.

Fig. 17 is a schematic diagram illustrating the configuration of the incident face of the waveguide intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention.
Fig. 18A and 18B illustrate the optical systems for uniform irradiation of laser beam according to

the other embodiments of the present invention, which apply the retardation plate to the cylindrical lens array for division; they are similar to Fig. 8A and 8B.

Fig. 19 is similar to Fig. 18B, in which two retardation plates are disposed in front and rear of the cylindrical lens array for duplication.

Fig. 20 illustrates the focus modulation to the cylindrical lens array for duplication; it's similar to Fig. 18B.

Fig. 21 A and 21B illustrate an example of using the waveguide as the laser beam division unit and the optical rotatory plate as the uniformity unit according to the other embodiments of the present invention, which are similar to Fig. 1A and 1B respectively.

Fig. 22 is a variant example of Fig. 21B, illustrating the optical system which obstructs the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through; it's similar to Fig. 21B.

Fig. 23 is a schematic diagram illustrating the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide in the optical system for uniform irradiation of laser beam according to the other embodiment of the present invention, which is similar to Fig. 21B.

Fig. 24 is a schematic diagram illustrating laser beam division in the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide, which is similar to Fig. 23.

Fig. 25 is a variant example of Fig. 21, illustrating the optical system for uniform irradiation of laser beam which comprises a half-wavelength plate and an optical path length compensating unit.

Fig. 26 is a variant example of Fig. 23, illustrating the optical system for uniform irradiation of laser beam which comprises a half-wavelength plate and an optical path length compensating unit.

Fig. 27A and 27B are schematic diagrams illustrating the optical system for uniform irradiation of laser beam which employs the cylindrical lens array for division and the half-wavelength plate; they are similar to Fig. 1A and 1B.

Fig. 28 illustrates the optical system which disposes alternately the half-wavelength plate and the retardation plate for the divided beams shown in Fig. 27A and 27B; it's similar to Fig. 27B.

Fig. 29 is similar to Fig. 27B, in which two retardation plates are disposed in front and rear of the cylindrical lens array for duplication.

Fig. 30A and 30B are schematic diagrams illustrating the optical system for uniform irradiation of laser beam in which each of the divided beams is shifted, i.e. misaligned and duplicated, via a

superposition and irradiation unit according to the other embodiments of the present invention, viewed from y-direction and x-direction respectively; Fig. 30C illustrates the profile of intensity of the irradiating beam in the optical system shown in Fig. 30A and 30B.

Fig. 31A, 31B and 31C are similar to Fig. 30A, 30B and 30C, which illustrate the configuration of the optical axis of the incident light intersecting obliquely the central axis of the waveguide.

Fig. 32A and 32B are schematic diagrams illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; they are similar to Fig. 8A and 8B respectively.

Fig. 33A and 33B are schematic diagrams illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; they are similar to Fig. 18A and 18B respectively.

Fig. 34 is a schematic diagram illustrating the optical system which comprises the superposition and irradiation unit for shifting and duplicating the divided beams on the irradiated area; it's similar to Fig. 27.

Detailed Description of the Invention

A laser beam division unit of the optical system according to the present invention divides the laser beam from a laser source into a plurality of divided beams which will pass through a superposition and irradiation unit. The superposition and irradiation unit makes the divided beams superposed and irradiated on the irradiated area. Herein the laser beam division unit enables each of the divided beams to have a width of more than 1/2 times of the spatial interference distance in the direction of a cross section of the laser beam, thus preventing the interference between the divided beams on the irradiated area and making the intensity distribution of the irradiating beam uniform.

Before being divided, two divided beams are readily interfered if they are adjacent to each other in the cross section of this laser beam. However, the interference can be reduced by means of making the width of each divided beam more than 1/2 times of the spatial interference distance.

The width of each of the above-mentioned divided beams is defined as that of the divided beam in the exit face of the laser beam division unit and in this case, the spatial interference distance refers to the spatial interference distance in the cross section when the laser beam from the light source is projected on the location of the exit face. It will be described in more detail hereinafter that the spatial interference distance relates to the interference occurring when two branches divided from the laser beam are superposed on the irradiated area, and the visibility to be described below is the minimum overlap distance of two divided beams when it becomes to 1/e.

In the present invention, the ratio of the divided beam width to the spatial interference distance in the direction of the cross section of the beam is more than 1/2, preferably more than $1/\sqrt{2}$, more preferably more than 1. That is, the width of the divided beam divided by the laser beam division

unit is desired to set to be more than $1/\sqrt{2}$ times of the spatial interference distance, especially 1 times or more.

The upper limit of the divided beam width is decided by the number of the divided beams, but the number of the divided beams is at least 5, and preferably 7 or more. Although it is more effective in flattening the intensity of the irradiating beam if the number of the divided beams is larger, it is not desirable that the number of divided beams is so large that the ratio of the divided beam width to the spatial interference distance becomes less than 1/2. The practical number of the divided beams is 5-7 and the ratio of the divided beam width to the spatial interference distance is set to 1 times or more.

The laser beam division unit divides the laser beam from the laser source and specifies the laser beam width, and the laser beam division unit can use the waveguide or the cylindrical lens array which divides the laser beam into the divided beams with said number in any one direction in the surface perpendicular to the optical axis.

The waveguide can utilize a hollow body or a solid light-transmission body with two reflecting faces mutually opposite. The hollow waveguide can utilize the object that arranges two mirror faces oppositely at certain spacing.

The solid waveguide is the light-transmission body which is transparent plate-like, and makes major faces on sides as the mirror faces and uses the two end faces for incident and exit irradiation. Such a waveguide can usually use the optical glass plate.

In the waveguide, the condenser lens which performs incidence of the exit beam from the laser source between the reflecting faces in the waveguide is included in the laser beam division unit.

From the exit face of the waveguide, we can obtain the divided beams which aren't reflected by the reflecting faces but pass through the waveguide, and two groups of the divided beams which are reflected from the opposite reflecting faces each time. The number of the divided beams will increase by 2 whenever the number of the times that the incident beams are reflected from the reflecting faces increases once.

However, the cylindrical lens array used as the laser beam division unit, in which a plurality of the cylindrical lenses with the cylindrical shape and the cross section taking the form of convex lens are arranged in parallel in the direction essentially orthogonal to the optical axis, can obtain the divided beams corresponding to each of the tiny cylindrical lenses. In the laser beam division unit which uses the cylindrical lens array, a collimator is preferably included so that the collimated light is incident in the cylindrical lens array.

The other form of the optical system according to the present invention comprises an uniformity unit comprising a optical delay unit and a rotatory unit.

In the present invention, the optical delay unit has the function that make one of the adjacent

divided beams divided by the laser beam division unit relative to the other be delayed a longer distance than the temporal interference distance of the laser beam, thereby reducing and even preventing the interference occurring between the adjacent divided beams.

The optical delay unit preferably utilizes the light-transmission body for delaying beam, i.e. a retardation plate, which is inserted in the spatially separate optical path of each of the divided beams divided by the laser beam division unit. At this moment, when each of the divided beams are projected reversely toward the laser beam from the light source, the retardation plate is inserted in at least either of the adjacent divided beams so that the optical path difference is established between the adjacent divided beams.

The retardation plate makes the optical path difference of the adjacent divided beams larger than the temporal interference distance of the laser beam, thereby preventing the interference between the divided beams when a plurality of the separate divided beams irradiate the irradiated area and are superposed. The optical path difference is determined by the thickness of the retardation plate (i.e. light-transmission length), the difference of refractive indexes of the retardation plate and air.

Based on the laser beam from the laser source, the retardation plate is inserted in the arrangement of every other one of the adjacent divided beams divided from the laser beam to produce the optical path difference mutually, thus producing the phase difference.

In the present invention, the uniformity unit further comprises the optical rotatory unit, which makes a polarization angle between the adjacent divided beams divided by the laser beam division unit essentially orthogonal so that the irradiating beam with profile of the required uniform intensity distribution is formed when the divided beams are superposed on the irradiated area. In this embodiment, by means of making the polarization angle between the divided beams mutually orthogonal, the optical rotatory unit can reduce the interference between the divided beams occurring when superposing each of the adjacent divided beams on the irradiated area so as to make the intensity distribution of the irradiation uniform.

Based on the laser beam from the laser source, the optical rotatory plate is inserted in the arrangement of every other one of the adjacent divided beams divided from the laser beam to produce an angle of 90 degrees between the polarization planes.

An example of the optical rotatory unit is a crystalline plate using crystal, which makes the polarization plane passing the divided beam relative to the polarization plane of the other of the divided beams be rotated an angle of 90 degrees. Such an optical rotatory unit is known as the half-wavelength plate. Herein the so-called "essentially orthogonal" allows the angle deviation of ±30 degrees when the polarization plane of one of the divided beams is orthogonal to the polarization plane of the other of the divided beams. In this way, even though the polarization planes of two divided beams is not orthogonal, but intersect obliquely, the interference between two divided beams is also reduced.

Other rotatory units can also use a Fresnel rhomb.

Furthermore, because the optical rotatory unit is insert in only one of the adjacent divided beams, the optical path difference relative to the other of the divided beams is produced, which causes the deviation of imaging location of these divided beams on the irradiated area. So, the optical path length compensating plate is inserted in the other of the divided beams so that the optical path length of the other of the divided beams in which the optical rotatory unit isn't inserted is essentially equal to that of this divided beam, thereby making the imaging of this divided beam and the other of the divided beams on the irradiated area distinct and making the intensity distribution of the superposed irradiating beam uniform.

For the configuration of the uniformity unit (i.e. the retardation plate and the optical rotatory plate), the superposition and irradiation unit comprises a duplication (image transferring) lens for duplicating the divided beams from the laser beam on the irradiated area. When the spatially separate regions of a plurality of the divided beams are formed by means of the duplication lens, the uniformity unit, such as the retardation plate etc. is inserted in such separate regions. For example, when the laser beam division unit is a waveguide, the retardation plate is disposed in the focal position where each of the divided beams converges.

For the simplification of the uniformity unit, it is expected that the structure or configuration of the waveguide doesn't produce the divided beams which aren't reflected but pass. As described below, this configuration can alleviate the interference on the irradiated area by inserting a single retardation plate or optical rotatory plate in a preset group of the divided beams without inserting in another group of the divided beams. It has the advantage of making the configuration of a single optical delay unit simple.

For this reason, it is expected that a shelter is inserted in the divided beams of the incident laser beam which aren't reflected from inner reflecting faces but pass through the waveguide.

Other forms can take the structure in which the laser beam incident in the waveguide is made to be asymmetrically incident relative to the central axis of the waveguide. Thereby, in the waveguide, the optical axis of the laser beam incident in the waveguide is made to intersect obliquely the central axis between the reflecting faces of the waveguide so that the divided beams which aren't reflected from any reflecting faces but pass trough can't be produced.

Other forms use the above mentioned solid body with light transmission in the waveguide, however, the structure that the incident face and the central axis of the waveguide are intersected obliquely is employed, and the oblique incident face makes the incident light refracted. These forms have the advantage of utilizing all of the divided beams in the irradiation compared to the structure obstructing the divided beams which aren't reflected but pass through.

Since the optical paths at exit end of the cylindrical lens array are separate each other when the laser beam division unit is cylindrical lens array, other configurations of the uniformity unit can dispose the retardation plate and the optical rotatory plate in the optical path of the beam. At this time, several small retardation plates and optical rotatory plates can be disposed in every other one

of the beams divided by the cylindrical lens array.

In this way, a portion of several divided beams pass through the uniformity unit, and the superposition and irradiation unit makes the divided beams superposed and irradiated on the irradiated area. The projection of the irradiating laser beam shapes as a rectangle or straight line, and the intensity distribution of the irradiating beam in length direction is uniform.

In an embodiment of the present invention, the superposition and irradiation unit further comprises the function of making each of the divided beams be shifted mutually and duplicated to form the irradiating beam. The superposition and irradiation unit makes the divided beams divided by the division unit superposed and irradiated and shaped as rectangle or straight line on the irradiated area. But in this embodiment, especially the nonuniform intensity distribution is eliminated in length direction by making several divided beams be shifted in length direction of the irradiating beam. Such a superposition and irradiation unit preferably utilizes the cylindrical lens with lens aberration.

The optical system for uniform irradiation of laser beam according to the embodiments of the present invention is suitable for using in the annealing device, in which heating fusion of the amorphous silicon or polysilicon film formed by chemical vapor deposition on glass substrate is performed to polycrystallize or make it grow up to be a bigger and rougher crystal. Here the annealing is not only used for irradiating the solid film with laser to directly crystallize or re-crystallize, but also comprises temporary fusion of the solid film with laser and its crystallization in the subsequent coagulation process of the fusing film.

In the present invention, the laser source comprises a solid laser and a semiconductor laser, and the laser beam comprises the first harmonic and the higher harmonic in the solid laser and semiconductor laser. Especially when the irradiated area is a silicon semiconductor film, in particular amorphous silicon film, it is expected to utilize the second higher harmonic (double wave) or the third higher harmonic (double wave) to irradiate, except for the first harmonic of the solider laser, such as Nd:YAG laser, Nd:YLF laser, Yb:YAG laser, etc.. When these higher harmonics is in the wavelength range between 350~800nm, the amorphous film can appropriately absorb light and efficiently perform heating fusion.

Especially in the above-mentioned optical system for annealing, the linear irradiating beam which has a thin wide amplitude is formed on the silicon film surface. The irradiating beam scans the silicon film with the width of the beam in the direction orthogonal to the beam, heats it uniformly and rapidly, and then the silicon film is cooled to make it crystallize or grow up in the process of coagulation so that there is little interference pattern and the intensity distribution is uniform, whereby the crystal silicon film with wide amplitude, long shape and uniform high crystallinity is formed.

Embodiment 1

In the embodiment 1 of the present invention, an optical system for uniform irradiation of laser beam is shown in Fig. 1A and 1B, which can form the irradiating profile with the uniform

distribution extension in y direction and the straight-line form converged in x direction.

The optical system comprises a laser beam division unit 3, a superposition and irradiation unit 6 (61, 62). In this example, the laser beam division unit 3 divides a laser beam 1 into the divided beams 16a–16e with required quantity using a waveguide 4, and the divided beams are imaged as the irradiating beam 19 with straight-line profile on the irradiated area 90 by means of the superposition and irradiation unit 6.

In this embodiment, the laser beam division unit 3 comprises the optical system which makes the laser beam 1 from a laser oscillator incident in the waveguide 4, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, and further comprising a condenser lens 34 (a cylindrical lens) which condenses the beams in y direction and makes them incident in the waveguide 4.

The opposite main surfaces of the waveguide 4 have reflecting faces 41 and 42, which are perpendicular to the y direction in this drawing. The laser beam 1 passes through the incident face 43 and the exit face 44 between two reflecting faces orthogonal to the optical axis of the laser beam. The incident laser beam 1 passing between reflecting faces is divided into: the divided beam component emitted from the exit end, two divided beam components (m=+1, m=-1) reflected once (m=1) from either of the reflecting faces 41 and 42, two divided beam components (m=+2, m=-2) reflected twice (m=2) from two reflecting faces, and each of components reflected 3 times or more and emitted from the exit end.

The divided beam from the waveguide 4 is superposed and projected on the irradiated area 90 by the superposition and irradiation unit 6. The superposition and irradiation unit 6 consists of a y directional duplication lens 61 (a cylindrical lens) which duplicates the divided beams in y direction on the irradiated area, and a condenser lens 62 (a cylindrical lens) which condenses the beams in x direction. The y directional duplication lens 61 makes the beams pass through the x directional condenser lens 62 and extend to the specified length in y direction on the irradiated area 90, and the x directional condenser lens 62 makes the beams converge into a line in x direction, whereby the irradiating beam 19 with a straight-line profile is obtained on the irradiated area.

More particularly, although Fig. 2 shows the form of the laser beam which is emitted from a laser oscillator (not shown) , divided by the waveguide used as the laser beam division unit, the laser beam from the laser oscillator passes through the condenser lens 34 (the cylindrical lens) and is incident in the waveguide 4 via a focus F_0. In the waveguide 4, a portion of the incident beam has the divided beams which aren't reflected from the reflecting face but pass through (reflection unmber m=0), and there are two kinds of the divided beams in y direction which are reflected once from the opposite reflecting face 41 or 42 (m=±1), and there are also two kinds of the divided beams in y direction which are reflected twice from the reflecting faces 41 and 42 (m=±2), and each of the divided beams are emitted from the exit face 44. In the surface which is perpendicular to the optical axis and contains the focus F_0, there are focuses of the virtual image, such as F_{+1}, F_{-1}, F_{+2}, and F_{-2}. It can be observed that each of the divided beams is emitted from

these focuses of the virtual image via the opening of the exit face 44.

In Fig. 2, supposing the beam profile obtained when the laser beam passes through the condenser lens 34 without the waveguide and is extended via the focus and projected on the exit face 44 is a circle, the projected laser beam 14 can be decomposed into the components corresponding to a plurality of classifications of the divided beams respectively. Each component of the laser beam 1 is in the cross section. If the division is performed in order of m=-2, -1, 0, +1, and +2 in y direction, then it should be noted that the components emitted from the exit face 44 of the waveguide 4, i.e. the divided beams, are arranged in order of reflection number m= +2, +1, 0, -1, and –2 in y direction.

In Fig.2, only the arrangement of the divided beams of the components of m=0, +1, and +2 emitted from the exit face 44 of the waveguide 4 is shown, and the divided beams of m= +1 and m= +2 are mutually emitted to an opposite direction relative to the median face of the reflecting faces. On the other hand, the divided beams of m=-1, -2 are in symmetrical direction relative to the divided beams of m=+1,+2, which is omitted in this figure.

Fig. 3A illustrates the division width of the divided beams obtained when the laser beam passes through focus F_0 without being reflected by the waveguide 4 and is projected on the corresponding area of the exit face 44 of the waveguide. It is an example that the laser beam 14 which follows the circular profile of the Gauss distribution is divided into 7 divided beams by the waveguide.

In the waveguide 4, the adjacent divided beams are superposed repeatedly on its exit face 44. Thus, the boundary portions of the adjacent components based on the division of the laser beam 1 in Fig. 3B are consistent with the repeated portions of the divided beams in the exit face of the waveguide. For example, in Fig. 3A, the boundary portion III of the component of m=+1 is overlapped repeatedly on the boundary portion iii of the adjacent component of m=0 in the exit face of the waveguide, as shown in Fig. 3B.

If such divided beams are superposed and irradiated on the irradiated area 90 by means of the y directional duplication leans 61 and the x directional condenser lens 62, the interference arises in the irradiating beam on the irradiated area and the intensity distribution is wavelike.

Fig. 4 shows the example of the intensity distribution of the irradiating beam 19 obtained when two components from the divided beams (such as two component of m=+1 and M=0) are superposed and irradiated on the irradiated area 90 by means of the y directional duplication leans 61 and the x directional condenser lens 62. However, the adjacent boundary portions iii and III of the divided beams from the laser beam interfere each other severely, and also the boundary portions IV and ii of the divided beams from the laser beam which are far from each other present a small variation of the intensity distribution caused by the interference. In Fig. 4, the horizontal axis is the division width d and the vertical axis is the relative beam intensity. But Fig. 4 is the case in which the intensity distribution of the laser beam is approximate to the Gauss distribution and the division width d is equal to the spatial interference distance s.

The interference level caused by the superposition on the irradiated area depends on the ratio of the division width d to the spatial interference distance s of the laser beam in this position. Here the spatial interference distance s is defined as the distance between the center of both of $1/e^2$ circle (e is the bottom of a natural logarithm here), wherein the beam diameter D is specified as the diameter D of the circle at the time of $1/e^2$ optical axis intensity ($1/e^2$ circle) when the intensity distribution in the cross section of the laser beam takes Gaussian distribution, as shown in Fig.5. Now the visibility of the interference fringe is reduced to 1/e in the superposed irradiation area when the optical axis is shifted each other from the interference condition in which their optical axis are in common. Here the visibility is the value obtained when the difference between the maximum intensity and the minimum intensity in the interfered intensity distribution is divided by the sum of the maximum intensity and the minimum intensity, which is indicative of the scale of the interference level.

When the division width d of the laser beam is d=s/2, the visibility is approximate to 1 in the superposition portion of the irradiating beam on the areas close to each other of the adjacent divided beams, while the visibility becomes 1/e in the superposition portion of the irradiating beam on the areas far from each other of the divided beams. In the median areas, the visibility will reduce gradually from 1 to 1/e. In a preferred embodiment, the division width d is d=s/2 or more, and at this moment, the visibility will be reduced to 1/e below in the superposition portion of the irradiating beam on the areas far from each other of the divided beams.

When the division width d of the laser beam is $d = s/\sqrt{2}$ or more, the visibility will be reduced to $1/e^2$ in the superposition portion of the irradiating beam on the areas far from each other of the divided beams. In a preferred embodiment, the visibility will be reduced to $1/e^4$ below in the superposition portion of the irradiating beam on the areas far from each other of the divided beams.

As shown in Fig.2, the division width d is made to be d=s and the laser beam is divided into 7 by the waveguide 4. Fig. 6 illustrates the intensity distribution when the divided beams are superposed on the irradiated area, which presents the improved intensity distribution. In this drawing, the period T of the generated interference fringes is determined by $T = \lambda / \sin \Delta\theta$, wherein λ is wavelength, and $\Delta\theta$ is the difference between the incident angles of two divided beams on the irradiated area 19 which can cause the interference.

Embodiment 2

In this embodiment, the cylindrical lens array is used as another kind of the beam division unit. As shown in Fig. 8A and 8B, the optical system for uniform irradiation of laser beam comprises the optical system which makes the laser beam 1 from the laser oscillator incident in the cylindrical lens array 5, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, wherein the collimated light from the collimating lens 33 is incident in the cylindrical lens array 5.

In the cylindrical lens array 5, the cylindrical lens refers to the lens with the cylindrical shape in x

direction and the convex lens stacked in y direction toward the optical axis. However the cylindrical lens array in this example consists of five such tiny cylindrical lenses 5a~5e, whereby five divided beams are formed.

The divided beams 15a~15e from the cylindrical lens array 5 for beam division in y direction are incident in the cylindrical lens array 51 for further duplication disposed ahead, and the divided beams from the cylindrical lens array 51 for duplication are projected on the irradiated area 90 by means of the condenser lens 62 (the cylindrical lens) used to condense beam in x direction to form the irradiating beam 19 with a line-like profile that is uniform in y direction and is condensed into a thin line in x direction. An objective lens 63 is disposed between the cylindrical lens array 51 for duplication and the condenser lens 62.

Fig. 9A and 9B illustrate the division form of the laser beam using the cylindrical lens array 5. Different from the above-mentioned division using the waveguide, there is only the superposition without return when the beams divided by each of the tiny cylindrical lenses are superposed on the irradiated area. Thus, even though two adjacent divided beams are superposed on the irradiated area by means of the cylindrical lens array 51 for duplication and x directional condenser lens 62, there is no difference in the superposed intensity distribution in the interference of y direction.

Fig. 10 illustrates that the intensity distribution obtained by the superposition of two adjacent divided beams on the irradiated area is constant in y direction and its visibility is constant (i.e. 1/e) when the division width d is equal to the above spatial interference distance s.

Fig. 11 shows the intensity distribution obtained by the superposition of 7 divided beams which are divided by the cylindrical lens array 5 for division on the irradiated area, in which the division width d is d=s and there is a quite good distribution in y direction.

Embodiment 3

In the optical system according to an embodiment of the present invention, the uniformity unit comprises the optical delay unit which make one of the adjacent divided beams formed by the waveguide relative to the other be delayed a longer distance than the temporal interference distance of the laser beam. In order to prevent the interference occurring between the adjacent divided beams, the optical delay unit establishes the optical path difference between two adjacent divided beams, which is greater than the temporal interference distance.

This embodiment utilizes the optical delay unit, which shows the optical system utilizing the retardation plate with light transmission. As shown in Fig. 12A and 12B, the optical system uses the laser beam division unit 3 which utilizes the waveguide 4, two orthogonal cylindrical lenses (61,62) used as the superposition and irradiation unit 6, and the retardation plate 7 used as the optical delay unit. In this example, the waveguide 4 is the same as that of the embodiment 1, which divides the laser beam 1 into the divided beams 16a~16e with required quantity, and the divided beams are imaged as the irradiating beam 19 with straight-line profile on the irradiated area 90 by means of the superposition and irradiation unit 6.

In Fig. 12B, the retardation plate 7 (i.e. optical glass plate) used as the optical delay unit is inserted in any one of the divided beams apt to produce the interference mutually in the position where a plurality of the divided beams separate each other, thereby forming the optical path difference between the adjacent divided beams. In this example, the beams divided by the waveguide 4 are duplicated by the y directional duplication lens 61 and form the irradiating beam on the irradiated area by means of the x directional condenser lens 62, while the focus f of the beam is formed between the y directional duplication lens 61 and the x directional condenser lens 62 by means of the y directional duplication lens 61, and the glass plate used as the retardation plate 7 is inserted in the focal position f of either of the adjacent beams or front and rear of it to establish the optical path difference. In this example, the glass plates used as the retardation plates 7 are inserted in every other one of 5 divided beams while other divided beams will pass through the space between the adjacent retardation plates 7. By means of such an arrangement of the retardation plates 7, there is no interference between the adjacent divided beams occurring in the irradiating beam superposed on the irradiated area, thus essentially obtaining the profile of uniform intensity distribution.

The optical path difference $\triangle$a of the glass plate is given by the thickness a of glass, the refractive index n_1 of glass and the refractive index n_0 of air (usually n_0=1). $\Delta a = (n_1 - n_0)/n_1$.

The optical path difference $\triangle$a of the glass plate is set to be greater than the temporal interference distance $\triangle$L, that is, $\triangle$a >$\triangle$L, while the temporal interference distance of the laser beam is provided by $\Delta L = c\Delta t = \lambda^2/\Delta\lambda$. Here c is light velocity and $\triangle$t is interference time, and $\triangle\lambda$ is the wavelength width of the laser beam (spectrum width). The narrower the wavelength width of the laser beam is, the longer the interference distance is.

For example, in a Nd:YAG laser, for the beam with central wavelength λ=1.06μm, its spectrum width is $\triangle\lambda$=0.12~0.30mm, so the temporal interference distance is $\triangle$L=3.8~9.4mm.

Fig. 7 shows the relationship between the visibility of two divided beams from the adjacent regions of the laser beam on the irradiated area and the optical path difference established between the divided beams (i.e. the optical path difference $\triangle$a). When the optical path difference is equal to the temporal interference distance $\triangle$L, the visibility is reduced to 1/e, and the visibility will be further reduced by further increasing the optical path difference between the divided beams.

The glass thickness a, which provides the optical path difference between the adjacent divided beams more than the temporal interference distance $\triangle$L, can be obtained from these relationship. The thickness of the retardation plate can preferably provide the optical path difference which is 2 times or more of the temporal interference distance $\triangle$L, more preferably 4 times or more, by the configuration of the retardation plate. For example, the light source is the Nd:YAG laser, and when the retardation plate 7 as the optical delay unit uses quartz (its refractive index n_1=1.46), for the temporal interference distance $\triangle$L=3.8~9.4mm, the thickness of quartz glass a is 12~30mm.

Fig. 13 is a variant example of the embodiment 3, which illustrates the configuration of the optical system viewed from x direction. Except that the configuration of the optical delay unit 7 is different, the optical system for uniform irradiation of laser beam shown in Fig. 13 is substantially the same as those shown in Fig. 12A and 12B; however this system obstructs the divided beams that aren't reflected between the reflecting faces of the waveguide but pass through.

That is, the linear forward beams from the waveguide 4 shown in Fig.2, 3A and 3B with the reflection number m=0 are obstructed by a shelter 79 which is disposed in the focal position f behind the y directional duplication lens. Because the linearly forward beams with m=0 are blocked by the shelter 79 and can't reach the irradiated area, these beams make no contribution to the interference. So, the optical delay unit 7 is inserted in only either of groups of the divided beams (m=+1, -2) or (m=-1, +2) in symmetrical configuration, while no optical delay unit is inserted in the other group of the divided beams, whereby the interference between the divided beams on the irradiated area is alleviated. The optical delay unit 7 can use a single retardation plate 71 (such as a piece of glass plate or glass rod) to make one of groups of the divided beams (m=+1,-2) uniformly transmit, which has the advantage of simplifying the optical system.

The optical system in other variant example comprises the waveguide 4 and the optical delay unit 7. However the laser beam division unit formed from the waveguide doesn't involve the divided beams which aren't reflected in the waveguide 4 but linearly advance so that all of the divided beams are reflected at least once and the case in which the reflection numbers of two or more reflected beams are same is prevented. As shown in Fig. 14, such a laser beam division unit can take the structure which makes the optical axis of incident optical system of the laser beam division unit be at an oblique angle relative to the central axis of the waveguide.

As shown in Fig. 15,16A and 16B, supposing that the periphery component ① of the beams which are incident in the condenser lens 34 (the cylindrical lens) in the waveguide 4 is incident in the incident face of the waveguide 4 and then is reflected once from the reflecting face and emitted from the exit face; other beam components ②, ③, ④ from the condenser lens 34 are reflected twice, 3 times, 4 times respectively, and other components are reflected many times and emitted from the exit face. The emitted, divided beams are on the side of the exit face in Fig. 15 and indicated with the reflection numbers m=1~8.

Fig. 16A and 16B illustrate the configuration of the divided beams of the cross section of the laser beam in exit face 44 and the superposition of the divided beams in the exit face. The order of the reflection numbers indicates the order of the configuration of the divided beams in cross section of the laser beam. So, the divided beams with the order of the reflection number minus 1 are apt to interfere mutually on the irradiated area, and the retardation plate 7 as the spatial delay unit is disposed in either of the divided beams with order minus 1. As shown in Fig. 14, this retardation plate is disposed in the focal position f of the y directional duplication lens, and the group of the divided beams with even numbers of reflection (such as m=2,4,6) leans to one side relative to the group of the divided beams with odd numbers of reflection (such as m=1,2,3) so that a single retardation plate 72 is inserted in all of the divided beams with even numbers of reflection m=2,4,6.

In Fig. 16A and 16B, as described in above embodiment, the width d of the divided beam is set to be greater than or equal to 1/2 times of the spatial interference distance s, preferably $1/\sqrt{2}$ times or more, especially greater than or equal to 1 times of s.

Fig. 17 illustrates the other variant example in which no linearly forward divided beam is formed in the waveguide 4. In this example, the optical axis 40 of the waveguide 4 is made to be consistent with the optical axis 30 of the condenser lens 34 and the incident face 43 of the waveguide 4 is made to not be orthogonal to the optical axis but to be at an oblique angle. The incident beam 13 on the oblique incident face 43 is made to be refracted so that the divided beams reflected 1, 2, 3 etc. times other than the divided beams reflected 0 times can be obtained. In this example, by means of the focal position f of the y directional duplication lens, a single retardation plate 71 is inserted in the divided beams with the even numbers of reflection (such as m=2, 4, 6) or the divided beams with the odd numbers of reflection (such as m=1, 2, 3) in order to establish the optical path difference between the adjacent divided beams.

Embodiment 4

This embodiment illustrates the example in which the cylindrical lens array of the embodiment 2 is used as the division unit and the retardation plate is used as the optical delay unit that can delay the divided beams divided by the cylindrical lens array so as to prevent the interference.

In Fig. 18A and 18B, the retardation plate 7 as the optical delay unit is inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. In this example, each of the retardation plates 7 are inserted in every other one of the divided beams (i.e. the divided beams 15a, 15c, 15d) and no retardation plate is inserted in other divided beams 15b, 15d. Thereby, the interferences between the adjacent divided beams (for example, between the divided beams 15a and 15b, or between the divided beams 15b and 15c) on the irradiated area 90 are limited so as to make the intensity distribution caused by the interference of the superposed irradiating beam uniform.

Fig. 19 is a variant example of the optical system for uniform irradiation of laser beam shown in Fig. 18A and 18B, but a pair of the retardation plates 73 and 74 are disposed in the divided beams divided by the cylindrical lens array 5 for division and the focal position of the cylindrical lens array 51 for duplication in front of the cylindrical lens array 5 for division respectively. In this example, because two retardation plates 73 and 74 are disposed in front and rear of the cylindrical lens array 51 for duplication, the duplicated face and the duplicating face of the retardation plate are made to be conjugation relations, thus having the advantage of making the influence of diffraction on the irradiated area minimum.

Fig. 20 is a variant example of the optical system for uniform irradiation of laser beam shown in Fig. 18B, but the tiny lens 512 of the cylindrical lens array 51 for duplication in which the retardation plate 7 is inserted in the divided beams and the tiny lens 511 of the cylindrical lens array 51 for duplication in which no the retardation plate 7 is inserted in the divided beams are

made to have the different focal lengths so that their imagines on the irradiated area will became same. By means of inserting the retardation plate 7 for adjusting the optical path length in every other one of the divided beams arranged in y direction and divided by the cylindrical lens array 5 for division, the divided beams in which no retardation plate is inserted will result in the offset of the focal position f. However, the focal position of each tiny lens of the cylindrical lens array 51 for duplication can be used to compensate for the offset of the focal position f, thus making the intensity distribution of the interference caused by the superposed irradiating beam uniform.

Embodiment 5

In this embodiment, the optical rotatory unit is used as the uniformity unit to prevent the interference between the adjacent divided beams on the irradiated area and achieve uniformity. The optical system for uniform irradiation of laser beam comprises the waveguide used as the laser beam division unit, the cylindrical lens array used as the superposition and irradiation unit and the optical rotatory unit used as the uniformity unit. This optical system can form the irradiating profile with the uniform distribution extension in y direction and the straight-line form converged in x direction on the irradiated area. The laser beam division unit 3 utilizes the waveguide 4 to divide the laser beam into the divided beams with the required quantity and the superposition and irradiation unit makes the divided beams image as a straight-line profile on the irradiated area.

In the optical system of this embodiment, the uniformity unit comprises the optical rotatory unit which makes an angle of the polarization plane of either of the adjacent divided beams formed by the waveguide relative to the other essentially orthogonal. This optical rotatory unit can make the polarization planes of the adjacent divided beams mutually orthogonal to prevent the interference between the divided beams.

The optical rotatory unit performs optical rotation to make the relative angle of the polarization planes essentially orthogonal so that no interference arises between two adjacent divided beams. It is desirable to use the half-wavelength plate formed from quartz.

In Fig. 21A and 21B, the focus f is formed in front of the y directional duplication lens 61 (the cylindrical lens) before the waveguide 4 and the half-wavelength plate 8 used as the optical rotatory unit is disposed in this focal position. In this example, among the five divided beams from the waveguide 4, the half-wavelength plates 8 are inserted in only three divided beams with the reflection numbers m=0, m=+2 and m=-2, while no half-wavelength plate is inserted in the divided beams with other reflection numbers. Therefore, referring to Fig.2 and 3, the half-wavelength plate 8 is inserted in only either of two adjacent divided beams to make its polarization angle relative to the other divided beam essentially orthogonal. Thus, even though two adjacent divided beams which are combined at random are superposed on the irradiated area 90, there is no interference occurring between them. So, along with the limitation of the division width, the uniformity of the irradiating beam is improved by means of the superposition of the beams with essentially different polarization planes.

The use of the uniformity unit of this embodiment is to insert the half-wavelength plates 8 in every

other one of the divided beams in y direction, so it is necessary to provide the spacing between the half-wavelength plates 8 and 8 to make other divided beams pass through. The configuration and structure of this half-wavelength plate are somewhat complex.

In order to address this problem, in the structure shown in Fig. 22, the shelter 89 which is disposed in the focal position f at exit end of the y directional duplication lens 61 is used to obstruct the linearly forward beam with reflection number m=0. Since the linearly forward beam with m=0 can't reach the irradiated area, it doesn't contribute to the interference. So, a piece of half-wavelength plate used as the optical rotatory unit is inserted in either of groups of the divided beams (m=+1, -2) or (m=-1, +2) in symmetrical configuration relative to the linearly forward beam (m=0), while no the optical rotatory unit is inserted in the other group of the divided beams, whereby the interference between the divided beams 19 on the irradiated area is alleviated. On the other hand, the optical rotatory unit 8 can utilize a piece of half-wavelength plate 82 which makes one of groups of the divided beams (m=+1, -2) pass through together, which has the advantage of simplifying the optical system.

The shelter 89 can employ the solid which can absorb or reflect the laser beam, such as graphite, ceram, metal etc. The shelter 89 can also be assembled with a single optical rotatory unit 82 as a whole and be disposed in the focal position f of the y directional duplication lens 61.

In the variant example of Fig. 22, the center of the divided beam with m=0 is obstructed by the shelter 89. However, because the center of the divided beam with m=1 that is obstructed has the quite great energy, it will cause reduced efficiency without using it. It is uneconomical in this regard.

So, in the following variant example, the optical axis of the incident laser beam is made to intersect obliquely the central axis of the reflecting faces 41,42 of the waveguide relative to the waveguide so that the divided beams which aren't reflected between the reflecting faces 41,42 but pass through can't be generated, as shown in Fig. 14~16 of the embodiment 3. Then, the symmetry of the divided beams divided with reflection numbers m is destroyed, as shown in Fig.23, so that the divided beams from the waveguide vary from the divided beams reflected once (m=1) to the divided beams reflected many times (in this example, m=6) to prevent more than two divided beams from having the same number of reflection. Additionally, we can know from Fig. 23 that the divided beams with odd numbers of reflection m=1,3,5 and the divided beams with even numbers of reflection m=2,4,6 can be grouped into a group in the focal position f so that a single optical rotatory unit 8 can be used to simply configure the divided beams with odd numbers of reflection m=1,3,5 and the divided beams with even numbers of reflection m=2,4,6 without discarding the divided beams which aren't reflected (m=0) shown in Fig. 22. As shown in Fig.23, the polarization planes of the adjacent divided beams can be made to be essentially orthogonal by means of inserting a single optical rotatory unit 82 in the divided beams with even numbers of reflection, which has the advantage of preventing the interference between them in simple manner.

As other variant example of Fig. 23, the optical system shown in Fig. 24 comprises the waveguide 4 formed from the solid light-transmission body, which forms the incident face 43 of the

waveguide 4. The incident face 43 is not orthogonal to the central axis of the waveguide 4 but is appropriately oblique relative to the central axis so that the laser beam 12 from the condenser lens 34 on side of the light source is incident in the oblique exit face 43 and is refracted. As a result, the incident beam can be reflected at least once between the reflecting faces 41,42 and the divided beams which aren't reflected but pass through (m=0) aren't generated, as shown in Fig.23. The divided beams with gradually increasing reflection number can be established and then a single half-wavelength plate is used to divide the divided beams with even number of reflection or the divided beams with odd number of reflection to polarize these divided beams uniformly. At this moment, because the central axis of the waveguide is configured to be coaxial with the optical axis of the condenser lens 34, it is easy to design and assembly the optical system and it can achieve the same result as Fig.23.

In above described embodiment, the half-wavelength plate used as the optical rotatory unit is inserted in the adjacent divided beams to prevent the interference between them. However, the half-wavelength plate essentially prolongs the optical path length of the divided beam at same time so that the difference of the optical path lengths between the divided beam in which the half-wavelength plate is inserted and the divided beam in which no half-wavelength plate is inserted. In this way, if there is difference between the optical path lengths of two kinds of the divided beams, the imaging positions of the irradiating beams on the irradiating area are offset mutually so as to make the beam intensity profile on the irradiated area nondistinct, and the intensity distribution in width direction is extended, especially when the profile is a line form. Below, it is an example in which the optical path length compensating plate is inserted to prevent from generating the optical path difference.

In Fig. 25, the waveguide shown in Fig. 21B is used to divide beam and the half-wavelength plates 8 are inserted in every other one of the divided beams in the focal position f of the y directional duplication lens 61. In this example, the retardation plates 83 used as the optical path length compensating unit are inserted in the other of the divided beams in which the half-wavelength plates aren't inserted. In this example, the optical glass plate is used as the retardation plate 83, which thickness is set to produce the optical path length equal to that generated by the half-wavelength plate. There is no optical path difference between these divided beams generated on the irradiated area to guarantee distinctness of the irradiating profile.

Fig. 26 is an example in which the retardation plate 83 is applied to the example of Fig. 23. As above described, a single half-wavelength plate 82 is inserted in the group of the divided beams with even numbers of reflection (m=2, 4, 6) in the focal position f of the y directional duplication lens 61, while a single retardation plate 83 isn't inserted in the other of the divided beams with odd numbers of reflection (m=1, 3, 5), so as to eliminate the optical path difference between the beam groups. The special advantage of this example is to take a single half-wavelength plate 82 and a single retardation plate 83 as a whole, thus simply disposing them in the focal position f.

<u>Embodiment 6</u>

This embodiment is an example of the optical system for uniform irradiation of laser beam, in which the optical rotatory unit is used as the uniformity unit and the cylindrical lens array is used

as the laser beam division unit.

Fig. 27 shows the optical system which makes the laser beam 1 from the laser oscillator (not shown) incident in the cylindrical lens array 5. The optical system comprises the extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, wherein the collimated light from the collimating lens 33 is incident in the cylindrical lens array 5. The cylindrical lens array 5 refers to the lens with the cylindrical shape in x direction and the convex lens stacked in y direction toward the optical axis, which consists of five tiny cylindrical lenses 5a~5e, whereby five divided beams 15a~15e are formed.

The divided beams from the cylindrical lens array 5 for division in y direction are incident in the cylindrical lens array 51 for further duplication disposed ahead, and the divided beams from the cylindrical lens array 51 for duplication is projected on the irradiated area 90 by means of the condenser lens 62 (the cylindrical lens) used to condense beam in x direction to form the irradiating beam 19 with a line-like profile that is uniform in y direction and is condensed into a thin line in x direction. The objective lens 63 is disposed between the cylindrical lens array 51 for duplication and the condenser lens 62.

The half-wavelength plate 8 used as the optical rotatory unit is inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. However, the half-wavelength plates 7 are inserted in every other one of the divided beams (i.e. the divided beams 15a, 15c, and 15d) and no half-wavelength plate is inserted in other divided beams 15b, 15d. Thereby, the polarization angle between the adjacent divided beams (for example, between the divided beams 15a and 15b, between the divided beams 15b and 15c or other adjacent divided beams) is essentially orthogonal so as to suppress the interference on the irradiated area 90, thus making the intensity distribution caused by the interference of the superposed irradiating beam 19 uniform.

Other variant example is the example in which the half-wavelength plate includes the optical path length compensating unit. Fig.28 is an example in which the retardation plate 83 made of glass as the optical path length compensating unit is inserted in the corresponding other of the divided beams where no optical rotatory unit is inserted in (in this example, 15d, 15d). As above described, the half-wavelength plate 8 used as the optical rotatory unit is disposed in one of the divided beams, but the insertion of the half-wavelength plate 8 prolongs the optical path length of this divided beam. If there is difference between the optical path lengths of two kinds of the divided beams, the imaging positions of the irradiating beams on the irradiating area are offset mutually so as to make the profile nondistinct. In order to correct it, the retardation plate 83 used as the optical path length compensating unit which is used to prolong the optical path length is inserted in the other of the divided beams. In this example, the thickness of the optical glass plate used as the retardation plate 83 is set to produce the optical path length equal to that generated by the half-wavelength plate 8. Because the half-wavelength plate 8 and the retardation plate 83 are disposed alternately in Fig.27, the integrative uniformity unit can be formed by alternately connecting the half-wavelength plate 8 and the retardation plate 83 and taking them as a whole.

Fig. 29 is an example which, in the cylindrical lens array 51 for duplication of the optical system for uniform irradiation of laser beam shown in Fig. 27, the tiny lens 512 which the half-wavelength plate 7 is inserted in the divided beams and the tiny lens 511 which no the half-wavelength plate 7 is inserted in the divided beams are made to have the different focal lengths so that their imagines on the irradiated area will became same. By means of inserting the half-wavelength plate 8 for rotating the polarization plane in every other one of the divided beams arranged in y direction and divided by the cylindrical lens array 5 for division, the divided beams in which no half-wavelength plate is inserted will result in the offset of the focal position f. However, the focal position of each tiny lens of the cylindrical lens array 51 for duplication can be used to compensate for the offset of the focal position f, thus making the intensity distribution of each divided beam to be imaged on the irradiated area uniform.

Embodiment 7

In this embodiment, the optical system for irradiation of laser beam consists of the laser beam division unit which can divide the laser beam from the laser source, and the superposition and irradiation unit which can make the divided beams superposed and irradiated on the irradiated area. When the superposition and irradiation unit duplicates each of the divided beams on the irradiated area, each of the divided beams will be misaligned (i.e. shifted) mutually to form the irradiating beam.

In this embodiment, the waveguide is used as the laser beam division unit. The superposition and irradiation unit makes the divided beams from the laser beam division unit offset mutually and irradiate the irradiated area 90, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam.

In this embodiment, in Fig. 30A and 30B, the laser beam division unit comprises the optical system which makes the laser beam 1 from the laser oscillator incident in the waveguide 4, comprising an extender lens 31 for generating the collimated light, a y directional collimating lens 32 and a x directional collimating lens 33, and further comprising the condenser lens 34 (the cylindrical lens) which condenses the beams in y direction and makes them incident in the waveguide 4.

The opposite main surfaces of the waveguide 4 have reflecting faces 41 and 42, which are perpendicular to the y direction in this drawing, and the incident face 43 and the exit face 44 are orthogonal to the optical axis (in parallel with y direction). We can know from the above embodiment 1 in Fig. 2 and 3 that the laser beam 1 incident in the incident face 43 is divided into the component which isn't reflected from the reflecting face but passes through (m=0) and the component which is reflected from the reflecting face, in which the reflected component is divided into the component reflected once (m=1), the component reflected twice (m=2) and the component reflected three times.

The divided beam from the waveguide 4 is superposed and projected on the irradiated area 90 by the superposition and irradiation unit 6. The superposition and irradiation unit 6 consists of a y directional duplication lens 61 (cylindrical lens) which duplicates the divided beams in y direction

on the irradiated area, and a condenser lens 62 (cylindrical lens) which condenses the beams in x direction.

The y directional duplication lens 61 makes the beams pass through the x directional condenser lens 62 and extend to the specified length in y direction on the irradiated area 90, and the x directional condenser lens 62 makes the beams converge into a line in x direction, whereby the irradiating beam 19 with a straight-line profile is obtained on the irradiated area.

In this embodiment, as shown in Fig. 30B, the superposition and irradiation unit utilizes the aberration of the duplication lens 61 disposed in front of the waveguide 4 to make each of the divided beams 16a~16s somewhat misalign mutually and irradiate in y direction, thereby making the superposition of two tips of the superposed irradiating beam 19 in y direction on the irradiated area be misaligned so that its intensity distribution is step-like as shown in Fig. 30C. This alleviates large interference, and the irradiating beam with uniform intensity and less interference can be obtained in the range of uniform irradiation.

As the embodiment 3 shown in Fig. 14, in the example of Fig. 31A and 31B, the waveguide 4 is made of the transparent solid, in which its incident face 43 intersects obliquely its axial direction so that the incident beam is refracted. The beam reflected once from the reflecting face (m=1), the beam reflected twice (m=2), the beam reflected three times (m=3), and even the beam reflected six times (m=6) are emitted from the exit face, and the divided beams are made to irradiate the irradiated area 90 by means of the y directional condenser lens 61 and the x directional condenser lens 62. However, same as Fig. 30A and 30B, the divided beams are made to be misaligned and irradiate in y direction on the irradiated area 90 of the drawing by means of the lens aberration of the y directional condenser lens 61, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam.

The following variant example illustrates the optical system for laser beam irradiation in which each of the divided beams are offset mutually and duplicated to form the irradiating beam on the irradiated area by the superposition and irradiation unit in the optical system comprising the cylindrical lens array as the laser beam division unit.

Fig. 32A and 32B comprise the extender lens 31 for amplifying the laser beam, the y directional collimating lens 32 and the x directional collimating lens 33, so that the collimated light is incident in the cylindrical lens array 5. The divided beams 15a~15e divided by the cylindrical lens array 5 form the irradiating beam 19 with line-like profile extending in y direction on the irradiated area by means of the cylindrical lens array 51 for duplication, the y directional objective lens (the cylindrical lens) 63 and the x directional condenser lens 62. Furthermore, the objective lens 63 is adjusted to make the divided beams 16a~16e from the laser beam division unit be misaligned mutually and irradiate the irradiated area 90 to obtain the irradiating beam 19, thereby preventing the interference between the divided beams on the irradiated area so as to obtain the uniformity of the irradiating beam in y direction. Then, as shown in Fig. 30C, the irradiation profile at two tips in y direction presents the step-like intensity distribution, which enables the range of the irradiating beam with uniform distribution to be obtained.

As shown in Fig.33A and 33B, in the variant example of this embodiment, the retardation plate 7 used as the optical delay unit is disposed between the cylindrical lens array 5 for division and the cylindrical lens array 51 for duplication to alleviate the interference caused by the adjacent divided beams on the cross section of the laser beam on the irradiated area. The effect of the reduced interference caused by the offset of each of the divided beams when superposed, which is produced by the objective lens 63, along with the effect of the reduced interference between the divided beams caused by the optical delay, enable this example to have the advantage of further reducing the variation in the intensity distribution caused by the interference.

In this embodiment, in the optical delay unit, the retardation plates 7 with light transmission are disposed in every other one of a plurality of the divided beams. The optical path difference which is greater than the spatial interference distance can be formed between the adjacent divided beams by making either of the adjacent divided beams pass through the retardation plate 7.

The following example illustrates the polarization unit which is used in the uniformity unit to make one of the adjacent divided beams essentially orthogonal relative to the polarization direction of the other. In the example shown in Fig. 34, the laser beam from the laser source first passes through the optical rotatory plate 71 to the extender lens 31, and the half-wavelength plates 8 used as the optical rotatory plate are inserted in the divided beams 15a~15e divided by the cylindrical lens array 5 for division in y direction. However, the half-wavelength plates 7 are inserted in every other one of the divided beams 15a, 15c, 15d and no half-wavelength plate is inserted in other divided beams 15b, 15d. Thereby, the polarization angle between the adjacent divided beams (for example, between the divided beams 15a and 15b, between the divided beams 15b and 15c or other adjacent divided beams) is essentially orthogonal so as to suppress the interference on the irradiated area 90, thus making the intensity distribution caused by the interference of the superposed irradiating beam 19 uniform. In this example, the half-wavelength plates 7 are inserted in every other one of the beams divided in y direction so that the polarized light irradiates the irradiated area 90 by means of the duplication lens. But, here the objective lens 63 is adjusted to make each of the divided beams be misaligned in y direction, thereby preventing the interference between the divided beams. When the misaligned beams irradiates the irradiated area 90, the intensity distribution of the irradiating beam 19 is step-like at two tips of the irradiating beam 19 in y direction but the uniform intensity distribution with less interference can be achieved in major portion other than two tips.

What is claimed is:

1. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section; and

a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area;

characterized in that the laser beam division unit makes the width of the divided beam greater than or equal to 1/2 times of a spatial interference distance in cross section direction of the laser beam cross section.

2. The optical system according to claim 1, wherein the division width of the laser beam is greater than or equal to the spatial interference distance.

3. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section;

a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area; and

an uniformity unit which makes the beam intensity on the irradiated area uniform;

characterized in that the uniformity unit comprises an optical delay unit which makes one of the adjacent divided beams relative to the other be delayed a longer distance than a temporal interference distance of the laser beam.

4. The optical system according to claim 3, wherein the optical delay unit is a retardation plate disposed in the region which separates a plurality of the divided beams spatially.

5. The optical system according to claim 4, wherein the laser beam division unit is a one-dimensional waveguide with the opposite reflecting faces, and the superposition and irradiation unit comprises a duplication lens for duplicating the divided beams from the laser beam division unit on the irradiated area, and each of the retardation plates is disposed about the focal position of the duplication lens for the divided beams.

6. The optical system according to claim 5, wherein the optical axis of the incident laser is configured to intersect obliquely the central axis between the reflecting faces of the waveguide relative to the waveguide so that the beams which aren't reflected but pass through can't be generated between the reflecting faces, thereby making either of two group of the adjacent irradiating beams pass through a single retardation plate.

7. The optical system according to claim 4, wherein the laser beam division unit is a one-dimensional cylindrical lens array for dividing the laser beam;

the retardation plates are disposed in the regions which separate spatially the plurality of the divided beams formed by the cylindrical lens array for division.

8. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section;

a superposition and irradiation unit which makes the divided beams superposed and irradiate an irradiated area; and

an uniformity unit which makes the beam intensity on the irradiated area uniform;

characterized in that the uniformity unit comprises an optical rotatory unit which makes the polarization direction of one of the adjacent divided beams relative to the other essentially orthogonal.

9. The optical system according to claim 8, wherein the optical rotatory units are disposed in the regions which separate spatially the plurality of the divided beams to make the polarization direction of either of the spatially separate, adjacent divided beams essentially orthogonal.

10. The optical system according to claim 8 or 9, wherein the laser beam division unit is a one-dimensional waveguide with the opposite reflecting faces, and the superposition and irradiation unit comprises a duplication lens for duplicating the divided beams from the laser beam division unit on the irradiated area, and the optical rotatory plate is disposed in the focal position of the duplication lens for the divided beams.

11. The optical system according to claim 10, wherein the optical axis of the incident laser intersects obliquely the central axis between the reflecting faces of the waveguide so that the divided beams which aren't reflected but pass through can't be generated between the reflecting faces.

12. The optical system according to claim 8 or 9, wherein the laser beam division unit is a one-dimensional cylindrical lens array for dividing the laser beam and the optical rotatory plates are disposed in the regions which separate spatially the plurality of the divided beams formed by the cylindrical lens array for division to make the polarization direction of either of the adjacent divided beams relative to the other essentially orthogonal.

13. The optical system according to claim 8 or 9, wherein an optical path length compensating plate is disposed in the other of the adjacent divided beams to make the optical path length of the other of the adjacent divided beams essentially equal to that of the one of the adjacent divided beams.

14. An optical system for uniform irradiation of laser beam, comprising:

a laser beam division unit which divides the laser beam form a laser source into the divided beams spatially in a beam cross section; and

a superposition and irradiation unit which makes the divided beams superposed and irradiate an irradiated area;

characterized in that the superposition and irradiation unit makes each of the divided beams be misaligned mutually and duplicated on the irradiated area to form an irradiating beam.

15. The optical system according to claim 14, wherein the laser beam division unit comprises a one-dimensional waveguide with the opposite reflecting faces or cylindrical lens array for division, and the superposition and irradiation unit is a cylindrical lens with the lens aberration.

Abstract

An optical system for uniform irradiation of laser beam is provided. The optical system includes a waveguide which divides spatially the laser beam from a laser source into the divided beams, a lens for superposition which makes the divided beams superposed and irradiated on an irradiated area, and a retardation plate which makes the beam intensity on the irradiated area uniform. The waveguide makes the width of the divided beam more than 1/2 times of the spatial interference distance in cross section direction of the laser beam cross section. The retardation plate makes the delay of the adjacent divided beams longer than the temporal interference distance of the laser beam, thereby alleviating the interference on the irradiated area. Another optical system includes a laser beam division unit which divides the laser beam into the divided beams, a superposition and irradiation unit which makes the divided beams superposed and irradiated on an irradiated area; and an uniformity unit which makes the beam intensity on the irradiated area uniform. The uniformity unit includes an optical delay unit which makes the delay between the adjacent divided beams longer than the temporal interference distance of the laser beam. The uniformity unit further includes an optical rotatory unit which makes the polarization direction between the adjacent divided beams essentially orthogonal.

Reference Number:

Fig. 1A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 1B

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 3B

均匀化 uniformity

Fig. 4

光强度分布（相对值） light intensity distribution (the relative value)

m=+1 和 m=0 的组合 combination m=+1 and m=0

可见度 visibility

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 5

可见度 visibility

Fig. 6

光强度分布（相对值） light intensity distribution (the relative value)

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 7

可见度 visibility

光程差 optical path difference

距离 distance

Fig. 8A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 8B

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 9B

均匀化 uniformity

Fig. 10

光强度分布（相对值） light intensity distribution (the relative value)

ii-III 和 iii-IV 的组合 combination ii-III and iii-IV

可见度 visibility

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 11

光强度分布（相对值） light intensity distribution (the relative value)

重合的光束在 y 方向的照射面上的位置 the position of the superposed beam on the irradiated area in y direction

Fig. 12A, 18A, 21A, 27A, 30A, 31A, 32A, 33A

聚光方向（x 方向）condensing beam direction (x direction)

Fig. 12B, 13, 14, 17, 18B, 19,20, 22, 23, 24, 25, 26, 27B, 28, 29, 30B, 31B, 32B, 33B, 34

均匀化方向（y 方向）uniformity direction (y direction)

Fig. 16B

均匀化方向 uniformity direction

Fig. 30C, 31C

照射强度 irradiation intensity

均匀照射的范围 range of uniform irradiation

Y 方向位置 position in y direction